8. Human Systems

Abstract

Climate change is likely to substantially impact many human systems and the local economy in the Skagit basin. In this chapter we discuss a number of impact pathways affecting human systems in the basin and their potential socioeconomic implications. Warmer temperatures and changes in the seasonality of precipitation are projected to significantly alter the hydrology of the Skagit River on which water resources systems depend, resulting in changes in the pattern of seasonal hydropower production, increases in the 100-year flood magnitude, and reduced summer instream flow. These changes will pose formidable challenges for water resources managers, utilities, and municipalities, particularly in the context of floodplain management. Increasing winter precipitation will likely impact urban stormwater management systems, increase landslide risks, and impact public safety in the transportation sector. Decreasing mountain snowpack will likely impact both winter recreation opportunities and white water recreation opportunities that depend on summer flow in rivers. Agriculture in Skagit County will be influenced by climate change via longer growing seasons, warmer, drier summers, wetter winters, warmer temperatures, and changing risks for pests, invasive plants (weeds), and diseases. Warmer temperatures (in isolation) are expected to result in degraded quality and/or decreased productivity of some crops such as spinach seeds, raspberries, blueberries and potatoes. Elevated carbon dioxide levels, however, may compensate for these impacts by increasing productivity in some crops. Increased flood risks from sea level rise and projected increases in river flooding would cause major damage to low-lying farms and urban development in the floodplain, impacting homes, businesses, water treatment plants, and transportation infrastructure such as bridges and roads. Sea level rise may also impact the ability to drain low-lying farmland using traditional tide gates. Warmer water temperatures, more severe and prolonged low summer flows, and potential habitat loss associated with projected sea level rise are projected to negatively impact coldwater fish species such as salmon, steelhead, and trout. With a few possible exceptions, climate change and its direct and indirect consequences are expected to have substantial negative impacts on the Skagit's current economy.

8.1 Water Management

8.1.1 Hydropower Resources

Hamlet et al. (2010) evaluated the potential effects of climate change on the demand for electric power and on hydropower generation for the Columbia River Basin and Washington State. They projected that per capita energy demand will increase in summer due to increased cooling degree days and more use of air conditioners, but decrease in winter due to warmer winters with fewer heating degree days. At the same time, projected system-wide hydropower generation for the Columbia River Hydro system increased in winter and spring but decreased in summer (Figure 8.1) corresponding to streamflow shifts associated with climate change (Chapter 5). By the 2080s, hydropower generation is projected to increase by 7.7-10.9 % in winter but decrease by 17.1-20.8 % in summer.

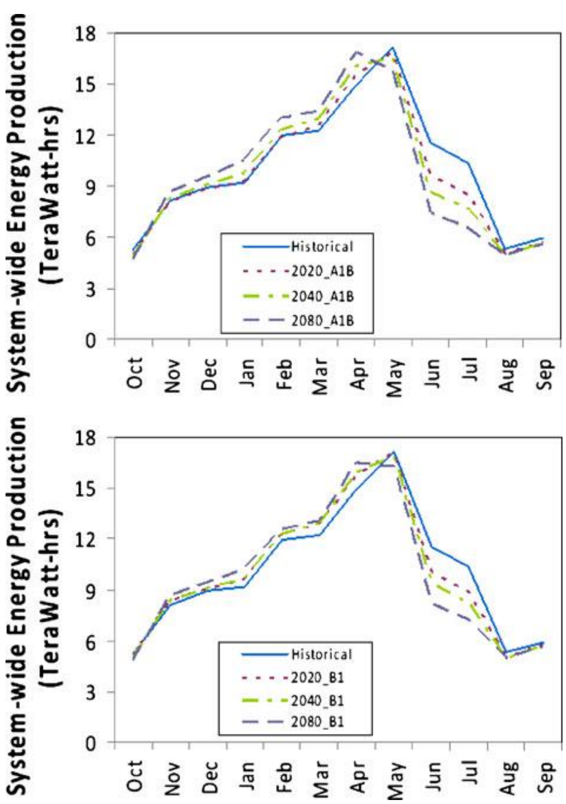

Figure 8.1 Simulated long-term mean, system-wide hydropower production from the Columbia River Basin for six climate change scenarios. Top panel shows results for the A1B scenario. Bottom panel shows results for the B1scenario (Source: Hamlet et al., 2010).

A recent study by Seattle City Light (2010) examined projected changes in hydropower generation for Seattle City Light (SCL) hydropower projects in the Skagit Basin under six climate scenarios, as shown in Figure 8.2. Seattle City Light (2010) used a Skagit Project operations model that maximizes the value of power while simultaneously adhering to regulatory requirements to maintain flood control pocket during the winter and early spring, refill Ross Reservoir by the end of June for National Park Service recreation season, and stay within allowable instream flows for fisheries downstream of Newhalem. The model does not include a summer low-flow criterion for fish. Annual power generation for the Skagit Project is projected to increase approximately 3 % by the 2020s, 5 % by the 2040s, and 9 % by the 2080s (Seattle City Light, 2010). The increased annual power generations are partly due to 1-2% of increased total annual inflow into Ross Lake (increased cool season precipitation in the scenarios) and dam operations that keep reservoirs at higher levels, creating higher efficiency (Seattle City Light, 2010). In comparison with the Columbia River Basin, the seasonality of Skagit River hydropower production is much more sensitive to streamflow timing shifts caused by warming and loss of snowpack (Chapter 5) (Figure 8.1). For the projected 2040s climate, for example, a 20 % increase in winter power generation was simulated for the SCL hydro system (Seattle City Light, 2010), whereas the same climate conditions produced about a 5 % increase in winter hydropower production for the Columbia River Basin (Hamlet et al., 2010). By the 2080s, peak hydropower generation in the SCL system shifts from July to January, which better matches existing Seattle electricity demand peaks. This projected increased generation is based on monthly flow data and may overstate increases. It assumes that Seattle City Light would be able to operate the three reservoirs in a manner that results in minimal spill events. In actual operations, large peak flow events could substantially reduce the cool season generation. Summer generation is projected to decline by 30% and could be problematic for meeting demand if use of air conditioning increases.

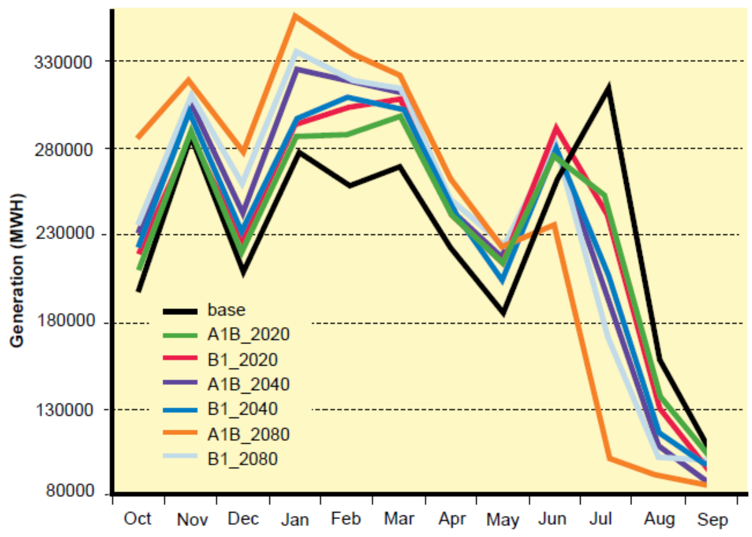

Figure 8.2 Effect of climate change on Skagit generation. Each line shows simulated ensemble median values for six climate change scenarios (Source: Seattle City Light, 2010).

8.1.2 Flood Control

The authorized storage space for flood control in the Skagit River is 194,000 acre-feet: 120,000 acre-feet at Ross Dam on the Upper Skagit River and 74,000 acre-feet at Upper Baker Dam on the Baker River (Table 8.1) (Chapter 1; FEMA, 2009). Lower Baker Dam, which has 116,700 acre-feet of usable storage (Table 8.1), can also provide additional flood protection on an on-call basis, but otherwise has no specific flood control requirements under normal conditions (Steward and Associates, 2004).

Table 8.1 Storage characteristics of major reservoirs in the Skagit River basin (Source: FEMA, 2009).

Reservoir	Flood Control Storage	Maximum Usable Storage
Ross	120,000 acre-ft	1,052,300 acre-ft
Diablo	0	76,220 acre-ft
Gorge	0	6,770 acre-ft
Upper Baker	74,000 acre-ft	180,128 acre-ft
Lower Baker	0	116,700 acre-ft

Currently, flood storage at Ross Dam is required from October 1 to March 15. Ross Reservoir is gradually drawn down to produce at least 20,000 acre-ft of storage by October 15, 43,000 acre-ft by November 1, and 60,000 acre-feet of flood storage by November 15. The full 120,000 acre-feet is required by December 1 (source: Seattle City Light). Similarly, Upper Baker Dam is required to provide 16,000 acre-feet of flood storage by November 1 and 74,000 acre-feet of flood storage by November 15 (Steward and Associates, 2004; Puget Sound Energy, 2006). If a flood event pushes forecasted runoff at Concrete to 90,000 cfs or higher, the U.S. Army Corps of Engineers operates Ross Dam in coordination with Upper Baker Dam to reduce flood peaks in the lower Skagit River valley (Puget Sound Energy, 2006; FEMA, 2009).

In an effort to increase flood protection in the Lower Skagit valley, Skagit County recently proposed increasing flood storage in Upper Baker Dam to 150,000 acre-feet and starting drawdown of the dam earlier in the fall, completing full drawdown by October 15 (one month earlier than current operations) (URL 1; Steward and Associates, 2005; Skagit County, 2008). The increased storage at Upper Baker Dam would likely be achieved by integrating Lower Baker Dam into the formal flood control system. An evaluation of the proposed Baker River flood control modifications by Steward and Associates (2005) showed that the proposed operations would provide lower peak flows on average, particularly for severe flood events, but would probably not reduce the magnitude of more frequent, moderately high flow events in comparison with current flood control operations. Steward and Associates (2005) also noted that refill timing needs to be adjusted to reach full storage by end of flood season because of the deeper reservoir drafting. Other alternatives being considered by Skagit County include increasing flood storage in Ross Reservoir from 120,000 to 180,000 acre-feet (URL 2). Actual flood storage in Ross Dam is also very dependent on hydropower operations, which typically evacuate the storage reservoirs below their required flood rule curves, resulting in more storage available for flood control by mid winter

Climate change is likely to shift the seasonal timing of peak flows in the Skagit River from spring to winter and increase the likelihood for more frequent and severe floods under natural (i.e. unmanaged or unregulated) conditions. For example, Figure 8.3 shows comparison of unregulated daily peak flows at the Skagit River near Mount Vernon for historical runs with those for the 2040s and for 2080s for Echam5 A1B scenario (a global climate model scenario which approximates the average conditions simulated by all models, see Chapter 3). For historical runs, daily peak flows occur 71 % (65 of 91 water years) in fall/winter, 21 % in spring and 8 % in summer (see Figure 8.3). For climate change, magnitude and frequency of fall/winter peak flows increase but those of spring and/or summer peak flows decrease substantially especially for the 2080s (see Figure 8.3). Cumulative distribution function (CDF) of unregulated daily peak flows (Figure 8.4) also shows that magnitude of unregulated peak flows increases as warming intensifies through the 21st century. The largest unregulated daily flood shows a 12% increase by the 2040s, and a 24% increase by the 2080s relative to the historical unregulated flood (Figure 8.4).

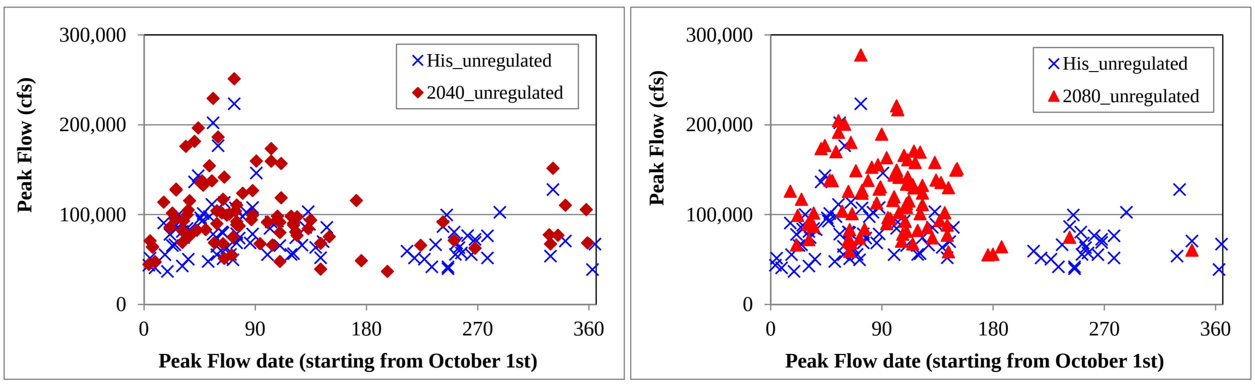

Figure 8.3 Comparison of unregulated daily peak flow dates and magnitude at the Skagit River near Mount Vernon for echam5 A1B scenarios for the 2040s (left) and 2080s (right) with those for historical runs.

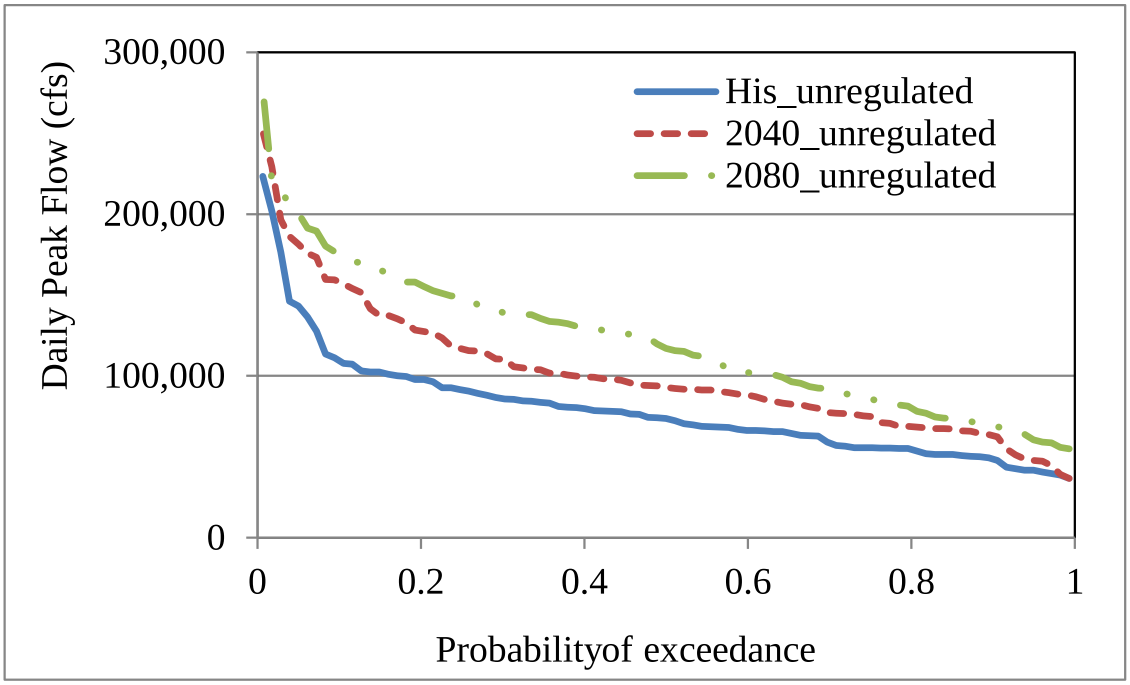

Figure 8.4 Cumulative distribution functions (CDFs) of unregulated (or natural) daily peak flows for the Skagit River near Mount Vernon for historical run and for echam5 A1B scenarios for the 2040s and 2080s.

To assess the combined effects of increasing natural flood risks and dam operations that determine impacts to regulated flow, a new integrated daily time step reservoir operations model was built for the Skagit River Basin. The model simulates current operating policies for historical flow conditions and for projected flow for the 2040s and 2080s associated with the Echam5 A1B scenario (see Chapter 3). By simulating alternative reservoir operating policies that provide increased flood storage and starting flood evacuation one month earlier, prospects for the adaptation are considered.

Regulated 100-year floods are less than natural floods in all time periods, however relative to the regulated baseline condition (the historical regulated 100-year flood under current flood control operations), the future regulated 100-year flood increased by 20% by the 2040s and 24% by the 2080s (Figure 8.5). Although increasing flood storage under the proposed alternative operations reduces 100-year flood risks, the reduction is only 3% for the 2040s and 7% for the 2080s (Figure 8.5). The alternative flood control operations are largely ineffective in mitigating the increased flood risks in the lower basin because inflows to the headwaters are a relatively small fraction of the total flow in the lower basin, and even fully capturing these inflows does not compensate for overall increases in flooding in the lower basin. It should also be noted that increasing flood storage would also entail many tradeoffs with other system objectives such as hydropower production, lake recreation, and instream flow for T & E fish species (Steward and Associates, 2004). Thus potential increases in flood storage would ultimately need to be weighed in the context of tradeoffs with other system objectives.

While these preliminary results for a single GCM scenario will need to be extended to include more GCM scenarios before final conclusions can be made, the preliminary results support the argument that climate change adaptation efforts will need to focus primarily on improving management of the floodplain to reduce vulnerability to increasing flood risk and sea level rise, rather than on increasing flood storage in existing headwater projects.

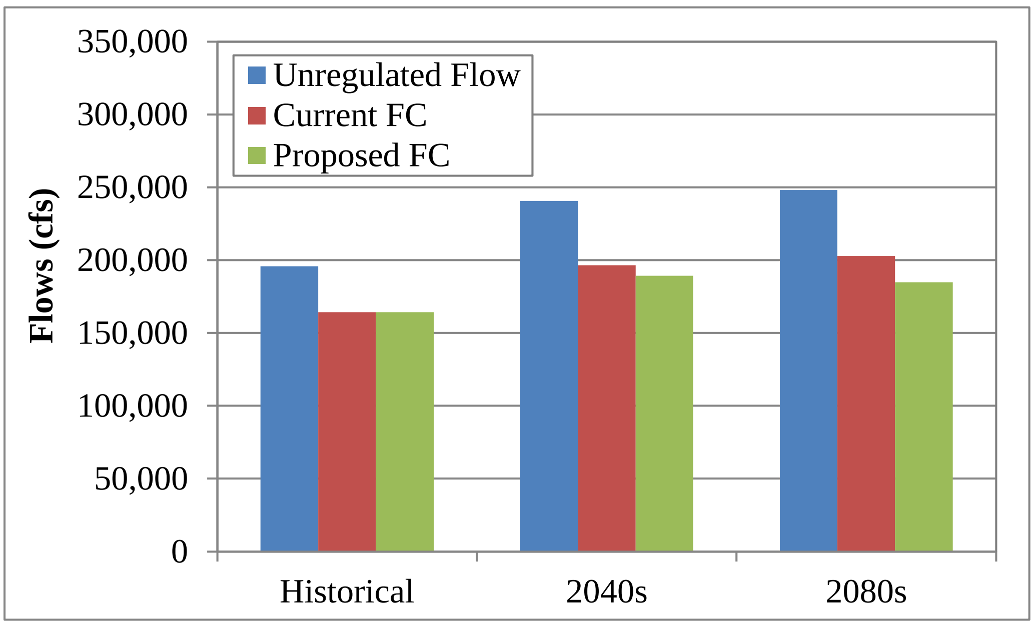

Figure 8.5 The magnitude of 100-year floods at the Skagit River near Mount Vernon for unregulated flows and for regulated flows under current flood control operations (CurFC) and alternative operations (AltFC). Historical run and echam5 A1B scenarios for the 2040s and the 2080s are considered.

Changing reservoir operating policies as an adaptation to climate change may also need to focus on altering the timing of refill so that reservoirs reach full storage during summer in order to meet the flow demands for T&E fish species and recreation needs. Lee et al. (2009), for example, showed that re-optimized flood rule curves for the Columbia River basin for a climate change scenario improved reservoir refill statistics and lowered flood risks by altering the timing of refill and decreasing the amount of flood storage. More detailed flood regulation studies are needed to explore potential adaptation strategies to the increased flood risk projected for the Skagit under warming scenarios. Although the hydrology of the Skagit and its climate sensitivity is considerably different from Columbia, the use of optimization to evaluate flood control alternatives (Lee et al., 2009) is likely a viable approach.

8.1.3 Stormwater Management

Although changes in average annual precipitation from global climate models (GCMs) show a very low signal to noise ratio (e.g. the systematic changes are small relative to the observed year-to-year variability), most GCMs project substantial increases in precipitation during the winter season (Chapter 3). Simulations by two regional climate model (RCMs) (Chapter 3) also showed substantial increases in the extreme rainfall magnitude for the next 50 years (Salathé et al. 2010). However, the magnitude of projected changes varies substantially by region and by model and future changes may be difficult to distinguish statistically from natural variability (Miles et al., 2010; Rosenberg et al., 2010). Despite these uncertainties, the general projections for more intense rainfall raise the concern that stormwater infrastructure designed using historical rainfall records may not perform adequately if extreme precipitation substantially increases. Additional RCM studies are currently underway to attempt to better characterize future storm intensity and flood responses, but results have not yet been published.

Sea level rise may also affect stormwater management. Stormwater outfalls in low-lying areas may be inundated (or provide inadequate drainage due to low slope) and may need to be relocated to higher locations, resulting in the potential need for some systems to be completely redesigned (SITC, 2009). A similar issue exists for tide gates used for agricultural drainage, as discussed in section 8.2

8.1.4 Recreation

The Skagit River offers opportunities for camping, fishing, picnicking, hiking, horseback riding, mountain biking, and pack and saddle trips (National Park Service, 2009). For example, Baker Lake is famous for trout fishing and Ross Lake also offers high quality sport fishing in summer (National Park Service, 2009). River recreation activities in the Skagit basin include river floating, kayaking, canoeing, and motor boating (National Park Service, 2009). Boat ramps are located at Baker Lake, Gorge Lake, Diablo Lake, and the north end of Ross Lake at Hozomeen (National Park Service, 2009). Winter recreation such as skiing, snowmobiling, snowshoeing, cross-country skiing, and sledding is available in the Mt. Baker National Recreation Area (National Park Service, 2009). The Skagit River also offers excellent wildlife viewing opportunities (National Park Service, 2009).

Increased temperature and changes in precipitation are likely to cause less snowfall, less snow accumulation, earlier snowmelt, and reduced summer flow (Chapter 5). These changes could have negative impacts on winter recreation and some water-related recreation (Morris and Walls, 2009; Econorthwest, 2009, 2010; Mickelson, 2009). Opening and closing dates for winter recreation depend on snow levels each year. Therefore less snowfall and reduced snow accumulation would likely shorten the winter recreation season (Morris and Walls, 2009). Low quality snow associated with climate change would also affect the demand for winter recreation days, particularly for ski days (rain during the ski season) (Morris and Walls, 2009; Econorthwest, 2009, 2010). Reduced summer flow could cause summer streamflow levels to fall below critical levels for some water-related recreation, such as river rafting and kayaking, and consequently have impacts on water-related recreation industry (Morris and Walls, 2009; Econorthwest, 2009, 2010; Mickelson, 2009). For example, a streamflow of about 3,500 cfs is required for rafting in the Sauk River (Mickelson, 2009). As shown in Figure 8.6, reduced summer flow would not adversely affect rafting early in the season (May) but is likely to reduce the possibility of rafting in July, particularly by the 2080's (Mickelson, 2009).

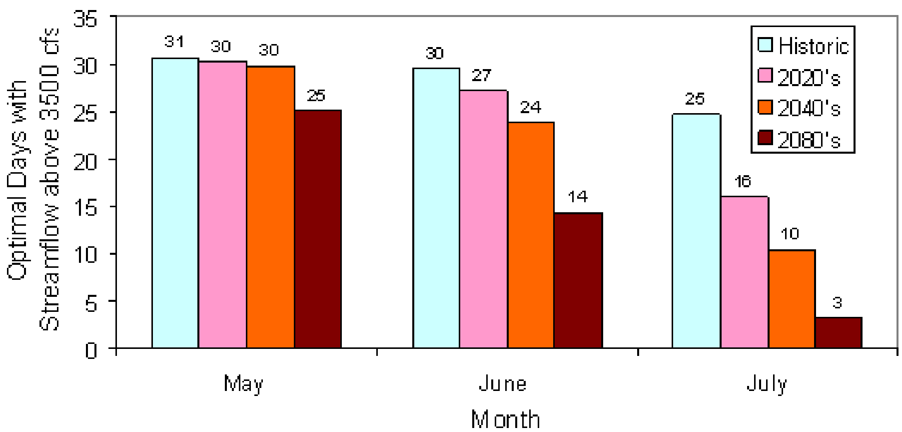

Figure 8.6 Number of optimal rafting days with streamflow above 3500 cfs per month for the Sauk River (Source: Mickelson, 2009).

The hypothesized reduction of salmon and steelhead populations (Chapter 7) would have an impact on the fishing industry in the Skagit River (Morris and Walls, 2009). Additionally, more frequent forest closures due to increased wild fire (Chapter 7) could reduce opportunities for outdoor activities such as hiking, mountain biking, wildlife watching and scenic tours (Morris and Walls, 2009; Econorthwest, 2009, 2010).

8.2 Agriculture

Agriculture is the leading industry in Skagit County (URLs 3 & 4; Hovee and Company, 2003). About $300 million worth of crops, livestock, and dairy products are produced in approximately 100,000 acres of Skagit County (URL 3). Over 90 different crops are grown in the County. Major crops include blueberries, raspberries, potatoes, sweet corn, cauliflower, broccoli, squash, pumpkins, tulips, and Jonagold apples (URLs 3 & 4; Washington State University, 2007; Hovee and Company, 2003). Skagit County produces about half of the spinach seed, table beet seed and cabbage seed for the United States (URL 4; Washington State University, 2007; Hovee and Company, 2003). Skagit County agriculture also provides habitat for thousands of migrating water birds such as swans, snow geese, and ducks (URL 3).

The effects of climate change on crop productivity has been evaluated at the global and regional scale in several large scale studies (IPCC 2007; Tubiello et al., 2002; Thomson et al., 2005; Stöckle et al., 2010). At the most basic level, crop production is impacted by climate change via water availability, temperature, and changing atmospheric carbon dioxide (CO_2) concentrations. Indirect impacts may include increased pests, invasive plants (weeds), or diseases. Tubiello et al. (2002) and Thomson et al. (2005) showed that projected warmer temperatures would (in isolation) decrease overall US agricultural productivity, but elevated CO_2 concentrations compensates for these losses by increasing productivity in some crops. Stöckle et al. (2010) found similar results for Washington State. Yields of winter wheat and apples in eastern Washington, for example, were projected to decrease in the 21st century without the effects of elevated atmospheric CO_2 concentrations; however, yields of these crops are projected to increase overall when projected CO_2 concentrations are considered (assuming no change in the availability of irrigation supply) (Stöckle et al., 2010). Tubiello et al. (2002) and Thomson et al. (2005) also noted, however, that the response of crop yield to climate change has to be evaluated at a local scale because agricultural impacts varies depending on local crop types, local weather, and especially local precipitation. As discussed below, impacts to drainage may also be an important factor.

Climate change is expected to influence local agriculture in Skagit County via longer potential growing seasons, drier summers, wetter winters, increased temperature, and changing risks for pests, invasive plants (weeds), and diseases (URL 5). Increased day time temperature is likely to degrade the quality and decrease the productivity of some crops such as spinach seed and raspberries (URL 5). Wetter winters with more frequent and severe rainfall events could cause root rot for some small fruiting plants such as raspberries, resulting in decreases in yield (URL 5). The quality of blueberries would likely be diminished due to increased nighttime temperatures (URL 5). Increasing temperatures and wetter winters are likely to create more favorable conditions for diseases, weeds, and pests (Stöckle et al., 2010), resulting in significant risks to economically important crops in Skagit County, particularly potatoes (URL 5). Projected warmer, drier summers could result in increased irrigation demand or increased moisture stress in areas without irrigation.

Most of the cropland and pasture land in Skagit County is located in the floodplain-delta area (Washington State University, 2007). The floodplain areas are protected by dikes and levees (Chapters 1 and 7) but these flood control structures are not able to protect agricultural areas from large floods (URL 6; Skagit County, 2007). Projected sea level rise and increased river flooding are likely to exacerbate the flood risk to Skagit County agriculture. Likewise drainage of low lying cropland is likely to be impacted by sea level rise, which will reduce the effectiveness of tide gates for draining the land. Without alternative measures (e.g. pumps), the viability of existing crop types and/or planting schedules may be compromised.

8.3 Flood Plain Development and Infrastructure

The Skagit flood plain, covering 90,000 acres, includes the entire floor of the Skagit River valley, the deltas of the Samish and Skagit Rivers and reclaimed tidelands adjoining the Skagit and Samish River Basins (URL 7; City of Anacortes, 2004), and is primarily agricultural but includes most of the County's urban development, manufacturing plants and major transportation routes (URL 7). More than 30,000 Skagit County residents live in the 100-year flood plain and would need to be evacuated in a current 100-year flood (Skagit County, 2007). During the flood of October 2003 (estimated to be a 100-year event), for example, residents from Fir Island, Clear Lake and Gages Slough area of Burlington, west Mount Vernon, and the Nookachamps basin were asked to evacuate, and homes in the flood plain were destroyed or damaged, with property damage estimated at $30 million (Skagit County, 2007; URL 8). Wastewater treatment, sewage collection system and major storm water pumping are also located in the flood plain and could be severely damaged during a major flood event (City of Anacortes, 2004; Skagit County, 2007; URL 9). As a result these facilities could be shut down for weeks, creating major human health risks and costing millions of dollars to repair (Skagit County, 2007). The Anacortes Water Treatment Plant could be inoperable for 45 days or more following 100-yr flood, cutting off safe drinking water to the cities of Anacortes and Oak Harbor, the town of La Conner, both petroleum refineries and NAS Whidbey for an extended period of time (URL 9; City of Anacortes, 2004; Skagit County, 2007).

Flood control structures such as dikes and levees protect development during small floods (at about the current 30-year return interval) but are not adequate for large floods (URL 6; Skagit County, 2007; FEMA, 2009). Events at the current 30-year return interval are projected to become more frequent in the future (Mantua et al., 2010; Hamlet et al., 2010). Dike and levee breaches, which are common during large floods, cause more damage to lands and structures behind them than would occur under natural flooding conditions (URL 6). For example, floods the size of those occurring in 1917 and 1921 would have breached the levees installed between Burlington and Mount Vernon, potentially causing loss of human life and a predicted 1.3 billion dollars in damage (Skagit County, 2007). More than 80 major dikes have failed in the basin since 1900 (City of Anacortes, 2004). These impacts are a major source of vulnerability for those living in the lower basin.

Projected sea level rise (Chapter 3) could increase the risk of tidal inundation for a significant number of properties in low-lying areas (SITC, 2009). Severe storm surges and resulting debris flows would cause major damage to existing property, infrastructure, and facilities (SITC, 2009). Areas most likely to be affected are gently sloping shoreline areas, or where surge would overtop banks, seawalls and dikes. Sea level rise when combined with tidal storm surges will almost certainly exacerbate the impacts of flooding and its associated effects (SITC, 2009). Increased winter precipitation combined with sea level rise would increase soil saturation and undermine slope stability, causing erosion of banks where shoreline banks are steeper than about a 3:1 ratio (slope height to slope length) (SITC, 2009). To reduce the property damage from inundation, relocation of future development or additional protection for existing infrastructure and facilities are both possible adaptive strategies (SITC, 2009).

Several flood damage reduction measures are currently being evaluated by the U.S. Army Corps of Engineers (USACE) and Skagit County (Figure 8.7) (URL 1). One of these measures (also discussed above) is to increase flood storage of the Skagit/Baker River reservoirs system and modify reservoir operations (URL 1; Steward and Associates, 2005; Skagit County, 2008). Other proposed flood hazard management plans are a) upgrading or modifying to existing levee system along the I-5 Corridor and b) constructing by-pass of extreme flows near the I-5 Bridge as illustrated in Figure 8.7 (URL 1; Skagit County, 2008). In extremely high-risk areas, relocation of existing development has been proposed. In the last century, for example, the town of Hamilton that has flooded more than 17 times and now floods every three years or so. Relocation of Hamilton to the other side of highway 20 is now underway (Figure 8.8, URL 11).

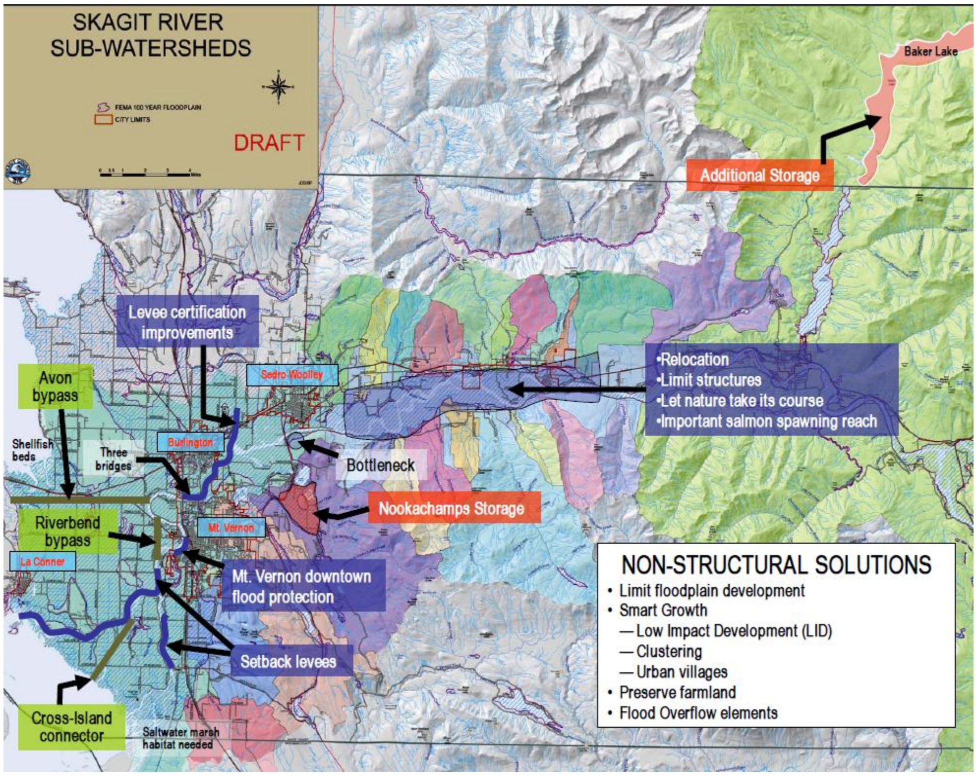

Figure 8.7 Proposed flood hazard management plan (Source: Skagit County, 2008).


Figure 8.8 Photo of town of Hamilton during October 2003 flood (Source: URL 10).

8.4 Roads and Bridges

Major highways in the Skagit are Interstate 5(I-5), State Routes 20, 9, 530 and 536 and would be closed in a 100-yr flood (Skagit County, 2007; URL 9). For instance, I-5 would be closed between Conway, to the south and Bow Hill, to the north during a 100-year flood (Skagit County, 2007; WSDOT, 2008). A railroad operated by Burlington Northern Santa Fe (BNSF) and Amtrak would also be devastated during a 100-year flood event. Projected changes in hydrologic extremes (Chapters 5 and 7) combined with sea level rise is expected to cause more frequent inundation of roads and bridges, impacting the transportation network and the local and regional economy (Skagit County, 2007; WSDOT, 2008). For example, Figures 8.9 and 8.10 show inundation of roads near La Conner and I-5 in Samish River north of Burlington during the flood of February 2006 and Jan 2009, respectively.

Figure 8.9 Inundation of roads near La Conner due to storm/tidal surge of February 2006, photos courtesy of John Doyle (Source: SITC, 2010).

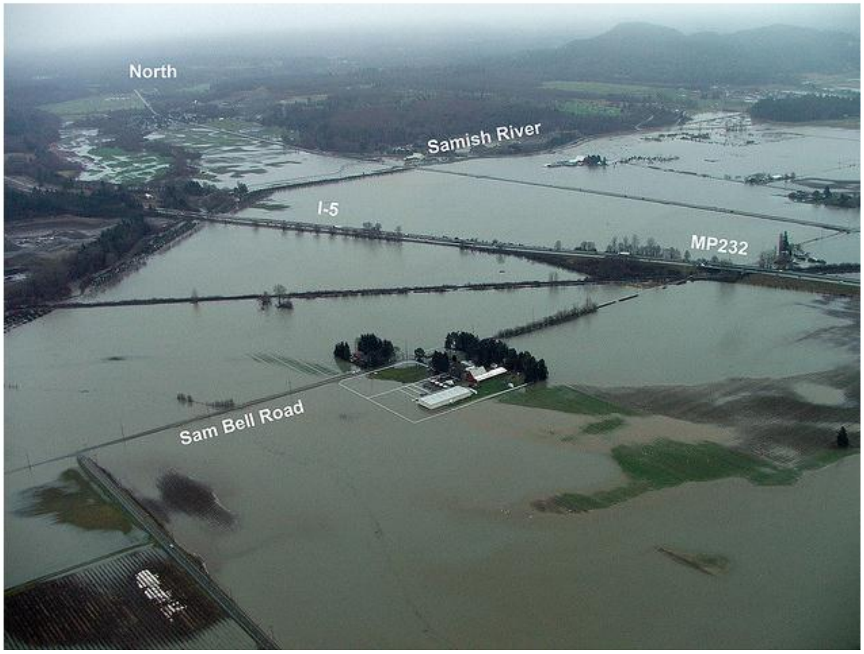

Figure 8.10 I-5 Flooding in Samish River north of Burlington during the flood of Jan 2009 (Source: URL 12).

Temporary inundation may not cause damage to roads and bridges but frequent and prolonged inundation would exacerbate erosion and pavement weathering from loosening of aggregate due to water saturated road base, possibly resulting in road or bridge failures (URL 6; SITC, 2009). For example, about 1,000 ft of the Sauk River Road just outside of the town of Darlington was eroded during the flood of October 2003 when a 100 year flood occurred in the Upper Skagit (FEMA, 2005; Lautz and Acosta, 2007). Intensified flooding during winter and resulting log jams increase the risk of damage to bridges (Figure 8.11). Debris flows, and rock fall could also damage bridges and pylons via increased scour or accelerate the deterioration of paved road surfaces, resulting in potential road and bridge failures (SITC, 2009). Increased and prolonged exposure to heat could cause more rapid break-down of asphalt seal binders and pavement softening, damaging paved roads and/or shortening road life (SITC, 2009).

Figure 8.11 Log jams behind the Burlington Northern Railroad Bridge in November 1995 flood (left panel) and in October 2003 flood (right panel) (Source: URL 10).

8.5 Economics

Potential economic costs in Washington to climate change have been evaluated by the Climate Leadership Initiative at the University of Oregon (2006) and Econorthwest (2009, 2010). Local economic impacts for the Skagit basin, however, are not available from these reports. There are probably significant differences between economic impacts for the Skagit basin (and Skagit County) and those estimated for Washington State as a whole. However, we use the Washington State economic analysis to broadly discuss analogous economic impacts in the Skagit basin and Skagit County.

Climate change and its consequences are likely to have negative impacts on Skagit's economy in several ways. In some cases, the economic harm comes from a change in climate itself, e.g. through changes in temperature, precipitation and extreme events (Econorthwest, 2009). Increased flood risks from more severe storms and sea level rise, for example, are likely to damage property, disrupt business and take lives (discussed above). Higher temperatures would reduce the productivity or quality of some crops (discussed above). In other cases, climate change indirectly influences the local economy by inducing changes in ecosystems. Warmer temperatures and increased summer moisture stress, for example, are expected to increase epidemic outbreaks of insects that kill pine trees (Littell et al., 2010) and other crops, resulting in reduced productivity (discussed above). Sea level rise is likely to cause habitat losses in low-lying areas and the Skagit delta (Chapter 6), causing reduction of economically valuable salmon and trout populations (Chapter 7). The possible negative impacts of climate change on the Skagit basin's economy are summarized as follows (Econorthwest, 2009, 2010):

- Water Resources: The water supply during summer may be insufficient to meet the combined demands for irrigation, municipal and industrial water demand, instream flow for fish and recreation (Mickelson, 2009). Diminished summer water supply has the potential to create economic impacts due to reduced access to (or increased cost of) water supply, reduced development potential in sub-basins already experiencing water stress, loss of recreation opportunities, or loss of environmental services that create impacts in other sectors (e.g. reduced salmon populations).
- Salmon Populations: Salmon populations are likely to decrease due to higher water temperature in the Skagit River and tributaries, more severe and prolonged low flow during summer, more intense flooding during winter and habitat losses due to sea level rise (Chapter 7). Because the salmon are a very important part of the Skagit basin economy, particularly for the Native American Tribes (Garibaldi and Turner, 2004; SITC, 2009), impacts to this resource would result in a relatively large impact to the local economy.
- Power Generation and Energy Demand: The mismatch between energy demand and local/regional hydropower generation (as discussed above) may result in economic losses due to the need to replace relatively inexpensive renewable hydropower resources with more expensive alternative energy sources (Hamlet et al., 2010) Although local utilities are expected to experience increased energy demand in all seasons due to population growth, individual consumers may see reduced heating bills due to lower heating degree days, a benefit of warmer winter temperatures.
- Agricultural Impacts: Climate change and its consequences may decrease the economic benefits associated with agricultural industry in Skagit County by degrading quality and the productivity of economically important crops in Skagit County (as discussed above). Poor drainage associated with sea level rise may limit the growing season or reduce the number of crop types that can be successfully grown (as discussed above). Although detailed studies are lacking, decreased summer water supply for irrigation may potentially reduce agricultural output in Skagit County. Because agriculture is the largest

industry in Skagit County, potential impacts to agriculture would result in relatively large economic impacts to the basin.

- Flood and Storm Damage: Increased tidal inundations from frequent, intense storms and sea level rise are likely to damage coastal property as well as inland areas reached by the tides. Flooding and associated impacts such as debris flows would cause damages to transportation infrastructure such as roads and bridges (Chapter 6). Major highway closures and resulting traffic delays related to a single 100-year flood event are estimated to cause economic losses estimated at over $15million (URLs 9 & 10).
- Recreation: Climate change is likely to reduce the economic benefits associated with the ski industry and some water-related recreation opportunities such as river rafting and kayaking as discussed above. More frequent forest closures due to increased forest fire would reduce opportunities available for activities such as hiking, mountain biking, wildlife watching and scenic driving (as discussed above). Winter access to some recreation areas such as bald eagle watching (Chapter 7) may improve, however, due to better driving conditions and less frequent road closures in moderate elevation areas (less snow). The hiking season would also be extended by reduced snow at lower elevations and earlier melt out of the spring snowpack at higher elevations.

8.6 Summary and Conclusions

Climate change and its consequences may influence human systems such as water management and agriculture and subsequently affect the local economy in the Skagit basin. Key findings on the implications of climate change for human systems and the local economy in the Skagit River include the following:

- Climate change is likely to cause a shift in streamflow timing, changing the seasonality for the Seattle City Light (SCL) Skagit hydropower system. Hydropower generations in the SCL Skagit system are projected to increase in winter but decrease in summer. By the end of the 21st century, the seasonal timing of maximum hydropower generation in the SCL system is likely to shift from summer to winter. Because per capita demand of electric power is projected to increase during summer for cooling but decrease during winter for heating, the seasonal timing shift of maximum hydropower generation could pose a challenge to hydropower operations. This mismatch between energy demand and local/regional hydropower generation may require replacing relatively inexpensive renewable hydropower resources with more expensive alternative energy sources, resulting in economic losses.

- A warmer climate and associated freezing level rise are likely to shift the seasonal timing of peak flows in the Skagit River from spring to fall/winter and increase the risk of flooding. Current and/or proposed flood control operations are projected not to be effective at mitigating these increased flood risks because current and increased flood storages on headwaters mitigate the impacts of natural floods only for the headwaters during high flow events, which is relatively small portion of the total flow in the lower Skagit River Basin. These results suggest that climate change adaptation efforts will need to focus primarily on improved management of the floodplain to reduce vulnerability to increasing flood risk and sea level rise, rather than on increasing flood storage on headwaters intended to reduce floods.
- The extreme rainfall magnitude is projected to increase during winter for the Skagit River, although actual changes in winter precipitation may be difficult to distinguish statistically from natural variability. Due to projected sea level rise, stormwater outfalls in low-lying areas may be inundated or provide inadequate drainage due to slope, requiring redesign and replacement.
- Climate change and its consequences are likely to influence recreation opportunities in Skagit County. Projected summer low flow is likely to reduce opportunities for some water-related recreation such as river rafting and kayaking. More frequent forest closures due to increased wildfires would reduce opportunities available for out-door activities such as hiking, mountain biking, wildlife watching and scenic driving. Less snowfall, reduced snow accumulation and earlier melt may improve winter access to some recreation areas by providing better driving conditions and less frequent road closures in moderate elevation areas and extend the hiking season at lower elevations but are likely to shorten ski season and degrade skiing conditions.

- Drier summers, wetter winters, and increased temperature may degrade the quality and the productivity of economically important crops such as spinach seeds, blueberries and raspberries. Increased disease, invasive plants (weeds), and pests due to warmer temperature are likely to reduce productivity of valued crops such as potatoes. Increased flood risk from the combined effects of sea-level rise and river flooding may also reduce agricultural productivity. Because agriculture is the leading industry in Skagit County, potential impacts to agriculture would result in relatively large economic impacts to the basin.
- Projected sea level rise and more frequent, intense flooding would increase flood risk at properties, infrastructures and transportation systems in the flood plain area. Failure of flood control structures such as dikes and levees during a flood event would further increase flood risk. The increased flood risks could cause major damages to low-lying farms and urban development in the floodplain, traffic delays due to major roads closures, and loss of human life, resulting in negative impacts on the Skagit's economy.
- Frequent and prolonged inundation as well as increased and prolonged exposure to heat could undermine the bridges or exacerbate deterioration of paved road surfaces, possibly resulting in road and bridge failures.
- In addition to economic impacts mentioned previously, climate change is likely to have negative impacts on Skagit's economy by causing changes in ecosystems. For example, economically valuable salmon and trout population is likely to decrease due to higher water temperature, more severe and prolonged summer low flow, more intense flooding during winter and habitat losses associated with sea level rise. Because salmon are a very important part of the Skagit's economy, a reduction in the salmon population would result in a relatively large impact to the local economy.
- Because current resource management strategies may not be adequate to meet the challenges caused by climate change as illustrated in flood control management, new strategies may be needed to adapt to future changes in climate. For example, increasing flood storage is proposed by Skagit County as one of the flood damage reduction strategies. Because changes in flood control operations will have an impact of other system objectives such as power generation, fish flow augmentation and recreation, more

detailed flood regulation studies are needed to explore the feasible dam operations under climate change to meet flood control requirement as well as other objectives.

URL 1:
http://www.skagitriverhistory.com/Skagit%20County%20Docs/SC%20FCZD/FCZD%20Plannin
g%20Memo.pdf
URL 2:
http://www.skagitriverhistory.com/Skagit%20County%20Docs/Flood%20Control%20Storage.pdf
URL 3: http://skagit.wsu.edu/agriculture/index.htm
URL 4: http://www.skagit.org/edasc-skagit-county-agricultural-links.php
URL 5:
http://www.goskagit.com/home/article/climate_change_could_have_dramatic_impact_on_local_
agricultural_scene/
URL 6:
http://www.co.snohomish.wa.us/documents/Departments/Public_Works/SurfaceWaterManagem
ent/Flooding/floodissues0910.pdf
URL 7:
http://www.skagitcounty.net/Common/Asp/Default.asp?d=Flood&c=General&p=hazard.htm
URL 8:
http://www.skagitriverhistory.com/PDFs/2010-01-
10%20Skagit%20CFHMP%20Chapter%206%20-%20LJK%20Draft.pdf
URL 9:
http://www.skagitcounty.net/Common/Asp/Default.asp?d=Flood&c=General&p=100yrflood.htm
URL 10: http://www.skagitriverhistory.com/Photo_Gallery.htm
URL 11: http://getdowntoearth.blogspot.com/2006_11_01_archive.html
URL 12: http://www.flickr.com/photos/wsdot/3192128998/

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